Experimental Results From Internetworking Data Applications Over Various Wireless Networks Using a Single Flexible Error Control Protocol

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'I'his paper describes results from several wireless field trials in New Jersey, California, and Colorado, conducted jointly by researchers at Bellcore, JPL, and US West over the course of 1993 and 1994. During these trials, applications communicated over multiple wireless networks including satellite, low power PCS, high power cellular, packet data, and the wireline Public Switched Telecommunications Network (PSTN). Key goals included:

1) Designing data applications and an API suited to mobile users.
2) Investigating internetworking issues.
3) Characterizing wireless networks under various field conditions.
4) Comparing the performance of different protocol mechanisms over the diverse networks and applications.

All the application and protocol software runs on PCs running UNIX: with a fixed server, and two mobile notebook clients (all client applications had an X-windows/Motif interface). We test four data applications (adapted for the mobile wireless environment): a) E-mail, b) Fax, c) Credit card verification, and d) Call Command. Mobile e-mail users can exchange text messages with any machine on the Internet. The Fax application sends and receives standard Group 111 faxes between a mobile user and any standard fax machine connected to the PSTN. For both the e-mail and fax applications, only a small mail/fax header is automatically sent to the mobile user. The user then decides whether to request delivery of the (potentially large) body of the message. Credit card verification simulates field service and sales people submitting charges for equipment or services anywhere in the radio coverage area. Call Command is a personal telephone management application that enables users to redirect telephone calls in real time. Upon receiving notification of an incoming call, the user may either route the call or reply with a text message (that is subsequently converted to speech). The calls may be routed to any local phone, to voice mail, or to another person. We describe the performance of each of these applications.

The API is designed to allow the applications more control and flexibility than standard APIs (such as the UNIX socket API). For example, an application can set the maximum allowed transmit time, and can receive status information about how much of a message had been acknowledged.

Users of future generation wireless information services will have diverse needs for voice, data, and potentially even video communication in a wide variety of circumstances. For users in dense, inner-city areas, low power PCS (voice and data) should be ideal. Vehicular-based users traveling at high speeds will need high power cellular networks. Packet data networks provide an excellent solution for users requiring occasional small messages. For users in remote or inaccessible locations, or for applications that are broadcast over a wide area, a satellite network would be the best' choice. To provide ubiquitous persona] communications service, it is necessary to integrate all these networks into one coherent system, with each network selected for its particular specialty/strength. Integrated together, they will provide a virtually seamless network for the users.

Our experiments constitute a first step toward universal personal communications by integrating networks to determine their overall performance. Our applications communicated over various combinations of networks based on: a) NASA's Advanced Communications Technology Satellite (ACTS) with JPL's ACTS Mobile Terminal (AMT), b) Bellcore's experimental low power PCS equiptnent, c) high power wireless cellular networks, d) a wireless packet data network, and e) the US PSTN.

NASA's ACTS system is an experimental K/Ka-band satellite developed by Martin Marietta Astro Space under contract to NASA. The satellite, which was launched into geostationary orbit at 100 degrees west longitude in September 1993, operates at a virtually untapped frequency spectra, K-(2O GHz) and Ka-bands (30 GHz). Another unique characteristic of ACTS is its highly concentrated spot beams (<0.20).

JPL's AMT is a proof-of-concept K/Ka-band mobile communications terminal intended to demonstrate the system techniques and high risk technologies needed to accelerate the commercial use of land-mobile systems at K/Ka-band. One such technique is the ability to integrate the mobile terminal for satellite communications with terrestrial personal communications equipment. To support this integration, the AMT Terminal Controller provides a digital interface between mobile client PCs and the AMT. PC data is converted to and from satellite frequencies in the K/Ka-band channel. The AMT supports multiple data rates ranging from 2.4 kbps to the 9.6 kbps rate used for this experiment.

The PCS system is an experimental low power micro-cellular system based on Bellcore's Personal Access Communication System (PACS). The experimental system could support up to 32 kbps; though for this experiment 19.2 kbps is used. The other networks are all commercial: including cellular networks (with 14.4 kbps error correcting modems), the RAM packet data network, and the PSTN.

Using measurements from the various networks, we will show that we can classify wireless networks (concentrating on the PCS and Satellite networks) as exhibiting either Rayleigh fading, Rician fading, or a combination of the two, Rician fading is characterized by a strong DC component due to a clear line-of-sight link. This results in a channel exhibiting generally low bit error rates. Rayleigh fading is characterized by longer-term shadowing effects causing long bursts of high error rates. All the wireless networks (both terrestrial and satellite) exhibit both forms of characteristics depending on the conditions. Initial results show a correlation between low-power stationary satellite tests (where the mobile unit is stationary) and PCS far from the transmitter (in the fringe reception areas). In addition, a correlation can be seen between mobile satellite tests and PCS near the transmitter, We will describe these results and draw preliminary conclusions.

The protocols are implemented in an experimental transport protocol TPE (comparable to TCP/IP, optimized for terrestrial wireless networks). In the experiments TPE acts as a common middle layer protocol between the application (via the API) and the network (all network communication is through standard RS232 interfaces, with data packets defined using the SLIP framing structure). Although existing protocols (e.g. TCP/IP) provide error control over conventional networks, wireless networks present significant new challenges. The radio environment introduces noise and multipath interference that can cause long periods of increased error rate, while host motion requires changing communication paths that can cause packet delay, disordering, duplication, and loss. Furthermore, scarce radio resources make bandwidth efficiency desirable.

We describe experimental results for different protocol mechanisms and parameters, such as acknowledgment schemes and packet sizes. We show the need for powerful error control mechanisms such as selective acknowledgments and combining, data from multiple transmissions. We highlight the possibility of a common protocol for all wireless networks, from micro-cellular PCS to Satellite networks. Although some of the mechanisms are already part of proposed broadband transport protocols; they are not widely used because of the additional computational complexity. In a wireless environment, where bandwidth is a scarce resource, we believe the improved efficiency is more urgently required, especially in the fringe reception areas.